

CONTROL OF *DERMACENTOR VARIABILIS*.¹ 3. AN
ANALYTICAL STUDY OF THE EFFECT OF LOW VOLUME
SPRAY FREQUENCY ON INSECTICIDE-STRESSED
AND NONSTRESSED POPULATIONS

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Abstract.—Nine field plots (each 0.4–0.6 ha) were selected along the south central part of Long Island, New York, to study the effect of insecticide spray frequency on a questing *Dermacentor variabilis* population. Assignment of treatment was made according to dominant vegetation, location and tick preferential habitat. Three plots received no treatment, 3 plots were sprayed with water (3 once, 2 twice, and one 3 times) and 3 plots were similarly sprayed with an emulsifiable formulation of naled. Plots were randomly monitored for tick density at weekly intervals. A total of 2,872 ticks was collected from all plots by dragging. Multiple and simple regression and exploratory data analyses were employed to determine normal or estimated tick populations at each plot throughout the adult tick season, rate of seasonal weekly decline of tick population, and the effect of insecticide spray frequency on the questing American dog tick population. Results indicated a 20% weekly exponential decay in numbers of questing adult ticks over the 1978 season. No effect was seen due to the water treatment. One spray of naled produced an 82% reduction of the questing tick population; 2 sprays, a 95% reduction; and 3 sprays, a 96% population reduction.

Investigations on the effect of insecticides or acaricides on tick populations in the field have been reported (Hoch et al. 1971; Mount et al. 1968, 1971; Smith et al. 1946; Wharton et al. 1976). Yet, little work has been done to delineate the effect produced on seasonal populations of questing American dog ticks by a series of well timed insecticide applications. The elaborate work reported by Smith et al. (1946) is the classic description of the biology of *Dermacentor variabilis* and has provided a foundation for further research into bionomics and improved control techniques.

Extensive tick control has been most commonly practiced in areas where ticks affect livestock (Drummond 1977; Teel et al. 1977; Wharton 1976). Area control of tick species affecting humans has become of recent interest to public health agencies along the east coast of the United States due to

¹ Acari: Ixodidae.

the increase of reported Rocky Mountain spotted fever cases (Benach et al. 1977; D'Angelo et al. 1978; Hattwick 1971; Loving et al. 1978).

Preliminary laboratory and field experimentation (White and Benach 1980) indicated the susceptibility of *D. variabilis* to naled (1,2-dibromo-2,2-dichloroethyl dimethyl phosphite), a nonpersistent insecticide. The development of fast-acting non-residual insecticides has benefitted public health agencies concerned with vector control. The advantages derived from the use of nonpersistent chemicals can be enhanced by a schedule of chemical applications during a particular tick season (Clymer et al. 1970).

Because control of the American dog tick is directed to the questing population, a certain percentage of ticks may be protected from the spray technique, e.g. in the soil, on hosts, or at the bases of vegetation. The population monitoring technique most often used for *D. variabilis* (i.e., dragging) measures only the questing population. The effect of chemical sprays may not be felt by the majority of ticks in a field or plot at any particular time. Dragging has been shown to be an inefficient (White et al. 1980) tool for monitoring actual field populations, and actual estimates of field populations have to be extracted from a combination of prior seasonal population data, abiotic factors affecting a particular plot (weather, vehicle traffic, etc.), potential favorable habitat, host availability and residents' complaints. A series of chemical applications can be made to compensate for the inherent weaknesses of field tick population estimates. Ticks that happen to be at the base of some vegetation may successfully escape contact with a chemical application. However, if these and other ticks are exposed at the time of subsequent applications, chances are greater that most ticks on the plot will, at some time, be subjected to contact with the acaricide.

A series of well timed chemical applications could lead to an effective *D. variabilis* control program. The present paper discusses the effect of 3 mist applications of naled at 4-week intervals on the questing population of *D. variabilis* over a 3-month season.

Materials and Methods

During the early spring of 1978, nine field plots (0.4–0.6 ha) were selected along the south shore of central Long Island, New York. Plot selection was based on dominant vegetation, location, and likelihood of supporting large numbers of *D. variabilis*. Three plots were chosen for their grass-dominant habitat, 3 for their grass-forb mixture habitat and 3 for their grass-forb-deciduous combination habitat. All plots were grouped into triplets or blocks that were similar in composition for the 3 parameters of vegetation, location and tick preferential habitat (Smith et al. 1946; Sonenshine et al. 1972). Treatment of each of the 9 plots was allocated a random, subject to the following constraints: (1) Three plots received no treatment (C1, C2, C3);

(2) Three plots received water sprays (as a control for the application procedure), 3 plots sprayed once (W1), 2 plots sprayed twice (W2) and 1 plot sprayed 3 times (W3) during the season; (3) Three plots received naled sprays, 3 plots sprayed once (D1), 2 plots sprayed twice (D2) and 1 plot sprayed 3 times (D3) through the adult tick season. Assignment of spray frequency among the 3 water-sprayed plots and 3 naled-sprayed plots was made at random. (See Table 1.)

A 24 (c) registration was received by Chevron Chemical Co. for the use of Dibrom 8 (naled) to control the American dog tick (EPA SLN No. 780008). Treatment for the D1, D2 and D3 plots consisted of application of 168 g actual Dibrom per ha (0.15 lbs/A). The naled formulation (1,2-dibromo-2,2-dichloroethyl dimethyl phosphate) was supplied courtesy of Chevron Chemical Co. Both water and chemical applications were delivered as previously described (White and Benach 1980). Plots to be sprayed once were sprayed during wk 1; plots sprayed twice were treated during wk 1 and 5; the plot sprayed 3 times was treated during wk 1, 5 and 9.

Weekly tick collections were made at each plot. Ticks collected at plot C3 were returned to the laboratory. On those plots that were treated during a specific week, collections for that week were made 24 h after the spray. White flannel cloth (1 m²) was used to collect questing ticks by dragging. Ticks attached to the flannel drag were counted every 10 m along a predetermined line of travel at the roadside edge of each plot (60–100 m).

All 9 plots could not be monitored for tick population on 1 day. Therefore, the group of plots was divided into 3 sets of 3 plots, each of which would be randomly monitored on 3 successive days of the week. In order to control for the effect of measuring the plots at different times of day and on different days of the week, predetermined random schedules were made resulting in 72 combinations of tick collection sequences in control, water-sprayed and naled-sprayed plots.

Statistical analyses were conducted using a randomized block analysis of variance model where blocks were similar for plot location, dominant vegetation and tick density. For analysis purposes, actual tick counts in each plot were normalized and transformed to base 10 logarithms. Analysis of data was conducted by 3 separate techniques; exploratory data analysis (Tukey 1977), multiple, and simple regression utilizing the analysis of variance model.

Actual field questing tick population data (Table 2) obtained by dragging were subjected to the following transformation:

$$Y_{ijk} = (X_{ijk}/N_{ij}) \times 100$$

Where i = indicator for treatments, i.e., $i = 1$ for control groups, $i = 2$ for water-treatment groups, and $i = 3$ for naled-treatment groups; j = the indicator for blocks, i.e., $j = 1$ for block 1, $j = 2$ for block 2, etc; and k is the

Table 1. Vegetational composition and number of *Dermacentor variabilis* collected at each of the 9 study plots over the entire season.

Plot	Vegetation*	No. ticks collected	Total no./treatment
C-1	g-f	261	
C-2	g	316	
C-3	g-f-d	526	1,103
W-1	g	11	
W-2	g-f	1,034	
W-3	g-f-d	80	1,125
D-1	g-f	65	
D-2	g	185	
D-3	g-f-d	394	644
		total	2,872

* g = grass, f = forb, d = deciduous.

index for week sequence. Therefore, X_{ijk} is the original total count of ticks in treatment i , block j and week k ; N_{ij} is the number of intervals in block j , treatment i from which ticks were collected and Y_{ijk} is the transformed total count of ticks in treatment i , block j and week k .

Then, in order to stabilize the week-to-week variability within plots, the transformed data were normalized using a log transformation:

$$Z_{ijk} = \log_{10}(Y_{ijk} + 1).$$

In view of the fact that each plot had varied original (pre-experimental) questing tick populations due to the dominant vegetation, and the plots were monitored for tick counts on a random basis over a 3-day period, a median polish process was utilized to produce a range of values about a 0.0 residual value (expected questing tick counts at a given point in time, Tukey 1977).

Because both C1 and W1 plots supported very few ticks, the data gathered during the same season from plot MR (White et al. 1980) replaced the data from C1. Data from plot W1 were dropped completely so that all analyses of effect of water were conducted on data from 2 plots, W2 and W3.

Results and Discussion

Dominant vegetational characteristics of each of the 9 plots and numbers of ticks collected in each plot throughout the 12-week experiment are listed in Table 1. All captured ticks (other than C3) were released in the 10 m section of each plot from which they were collected.

Exploratory data analysis.—By analyzing the transformed data for effect of week on the questing tick population (i.e., numbers of ticks over time),

Table 2. Actual numbers of questing *Dermacentor variabilis* collected from each plot during the 12-week study.

Week	Plot									
	MR*	C1	C2	C3	W1	W2	W3	D1	D2	D3
1	49	4	102	56	2	69	15	3	12	35
2	33	4	46	60	6	107	21	7	38	128
3	28	0	45	145	1	98	14	7	27	120
4	20	0	1	50	1	101	6	6	41	62
5	23	4	47	114	1	109	4	6	1	2
6	25	2	23	36	0	141	4	10	3	12
7	10	0	13	21	0	145	3	2	13	11
8	16	0	17	12	0	76	3	7	21	18
9	25	0	7	20	0	84	3	5	15	1
10	15	0	4	5	0	53	4	2	5	1
11	4	0	4	4	0	33	3	5	3	1
12	13	0	7	3	0	18	0	5	6	3

* MR = mark-recapture (White et al. 1980).

the fitted equation produced by exploratory data analysis is $Y = 0.5549 - 0.0913X$ which indicates an exponential decay rate of 19% ($10^{-0.0913} - 1 = 0.8104$, $1 - 0.8104 = 0.1896 = 19\%$) on the original scale (actual field collection data) which explains 88% of the variability of week effects ($F = 74.312$, d.f. = 11, $\alpha = 0.01$, $R^2 = 0.88$). By holding week and plot effect fixed, a noticeable drop of tick populations is apparent in plots D2 and D3 after treatment while control plots and water-treatment plots show no such relationship. The residual value indicates the transformed tick count that, based on data gathered from the control plots, would be expected to be present during each week. Values in excess of this threshold value indicate a population of ticks larger than that which would be expected; negative values indicate populations less than that which would be expected. Also evident is a resurgence of tick populations in the D block of plots shortly after the spray until the next chemical treatment.

Multiple regression.—By employing a more definitive analysis in a multiple regression process ($F = 3.369$, 75 df, $P = 0.00$, $R^2 = 0.4733$), further significant relationships can be shown to exist. Although the model is extremely complex and encompasses effects of individual treatments in each plot, the overall week effect and treatment effect are not easily distinguishable. The same transformed and normalized data were also used for this approach. The effect of week on tick populations is similar to that which resulted from exploratory data analysis with a 21% exponential decay rate of actual tick numbers ($F = 96.48$, 11 df, $\alpha = 0.01$, $P < 0.001$, $R^2 = 0.906$). However, a rebound (due to recruitment) of the tick population occurs dur-

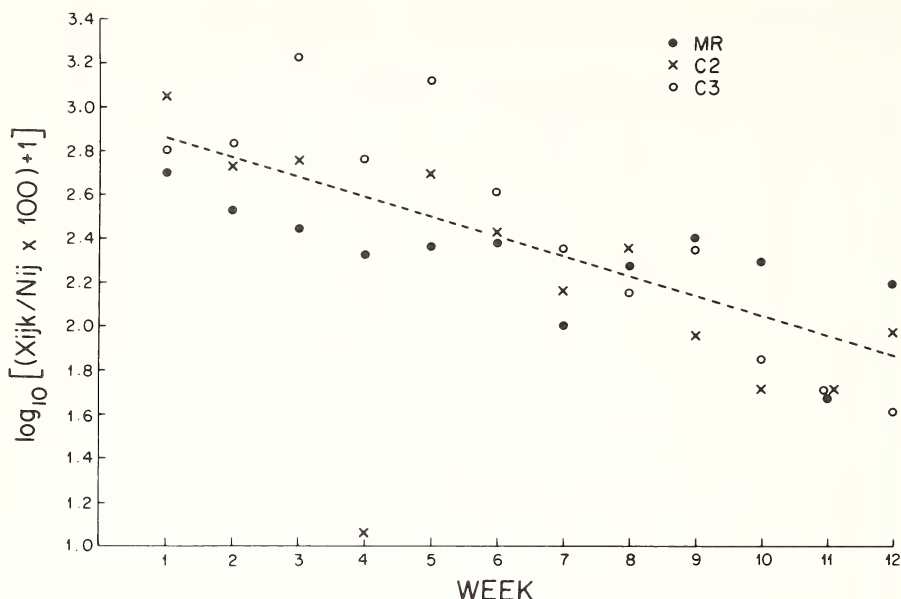


Fig. 1. Simple regression estimation of week effect on questing *Dermacentor variabilis* population transformed data.

ing weeks 5 and 8. The effect seen on the field tick populations by the water treatments was variable and probably due to the week effect included in this analysis. However, an 82% decrease of the questing tick population was seen after 1 application of naled on all 3 plots. On the two plots, D2 and D3, that were sprayed twice (during weeks 1 and 5), a reduction of 96% occurred. Likewise, an 87% reduction occurred on the plot that was sprayed for the 3rd time during week 9.

Simple regression.—By using a simple regression analysis the results become more clarified because each effect (week or treatment) is removed individually. For example, through use of the control groups to estimate the week effect on tick populations, the week effect can be extracted from the water-treatment group and the naled-treatment group to determine more precisely the effect of such treatment. Therefore, because the week effect has now been determined without the introduction of insecticide or mechanical stress on the population used for analysis, the actual results are more practical. Now the equation fitted for week effect becomes:

$$Z_{ijk} = 2.9252 - 0.0976X \quad (\text{See Fig. 1})$$

$$F = 33.2983. \quad 35 \text{ df}, \alpha = 0.05, \quad P < 0.01$$

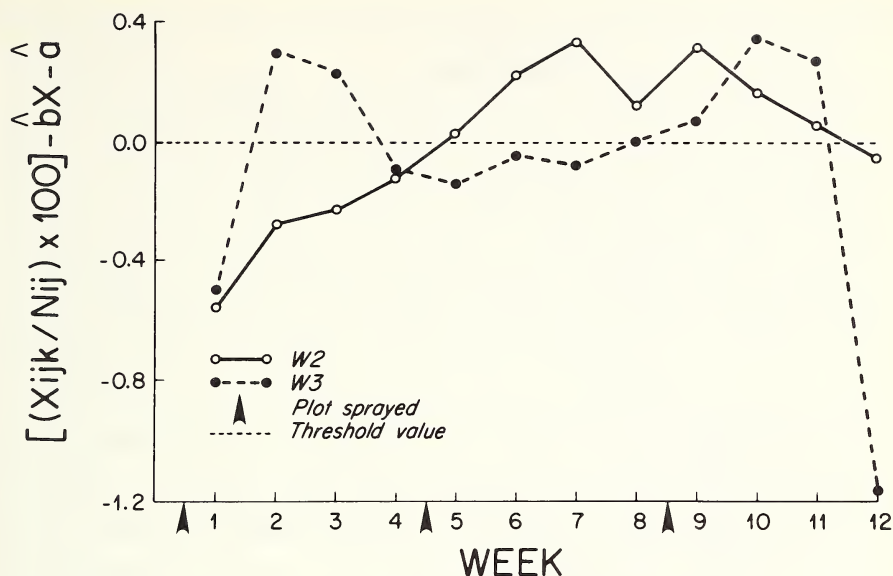


Fig. 2. Effect of water treatment on questing *D. variabilis* populations.

or, that the week effect on the tick population is exponential decay with a rate of 20% ($10^{-0.0976} - 1 = 0.7987$. $1 - 0.7987 = 0.2013 = 20\%$).

By extracting the week effect from the data gathered from the water treatment analysis, the effect of water on the tick population is nonexistent (Fig. 2). By extracting the seasonal tick reduction figures (week effects) from the data gathered from the naled treatment analysis, the effect on the questing tick population is pronounced (Fig. 3). Obviously, the effect of the 1st naled spray cannot be determined by simple regression because extensive tick sampling was not conducted prior to week 1. The 2nd naled spray reduced the population by 95% while the 3rd spray resulted in a 96% tick population reduction.

The preliminary laboratory and field experiments performed by White and Benach (1980) led to the conclusion that naled could prove effective in a large scale control program directed against *D. variabilis*. However, because naled is nonpersistent, a control program would have to rely on a series of well timed chemical applications over an entire season. For example, although all ticks were removed from plot C3 each week (Table 2), a large number of ticks were captured the following week, indicating 1 or both of the following: a large immigration factor or a poor sampling technique (White et al. 1980). In order to reduce tick numbers over an entire season, control should be carried out in a series of applications timed so

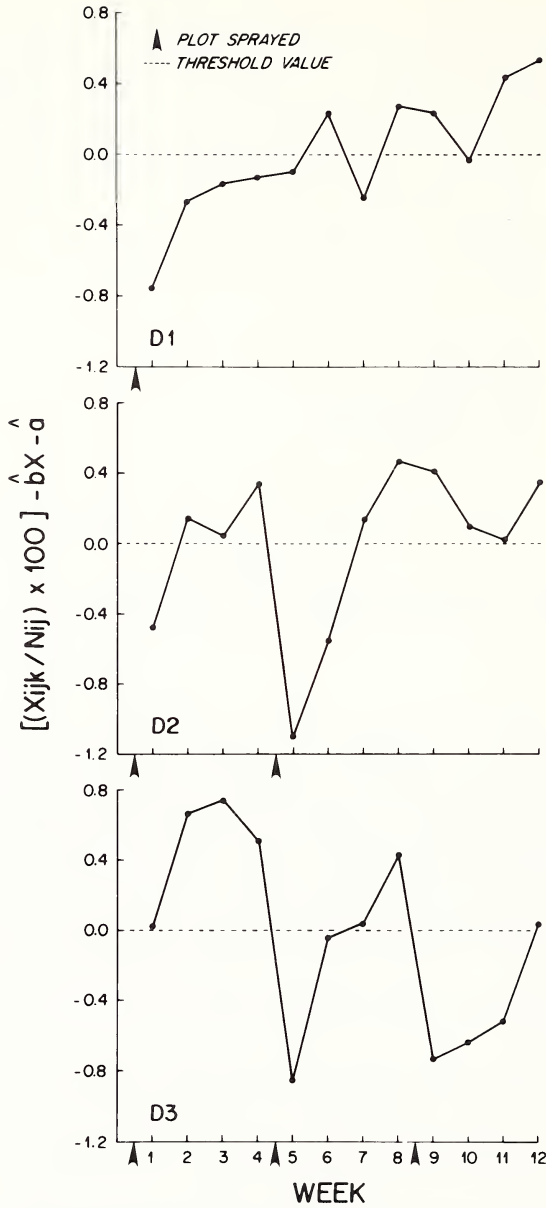


Fig. 3. Effect of naled treatment on questing *D. variabilis* populations.

that ticks do not reach a threshold value and so that chemicals are applied cost-effectively.

As can be seen in Table 1, tick densities were greatest in either the grass-forb or the grass-forb-deciduous mixed habitat than in grass alone. The greatest proportion of ticks present in the plots was seen in the first 4–7 weeks of the study, again dependent on the habitat. By incorporating all population data from the control plots (MR, C2 and C3, Table 2) a regression analysis resulted in the week effect, or effect of time within a season on the natural or nonstressed tick population. Over the season of study, a weekly exponential decay rate of 20% explained the general tick population depletion through mid-August and therefore represented our weekly threshold value.

By removing this week effect from the treatment effect (simple regression), a more precise description can be made. After each application of naled, there was an immediate decrease in the tick population followed by a gradual resurgence over the next 3 weeks. This would be expected because naled is efficient but nonpersistent. As the tick population increases to the expected value (0.0, Fig. 3), the effect of the previous naled spray has been eliminated at that point. An increase beyond the expected value necessitates a reapplication of naled to further reduce the questing population. The 2nd naled application resulted in a 95% and 97% reduction on plots D2 and D3 while the tick population continued to increase in D1.

After the 2nd spray, tick populations again started to increase to the expected value at a more rapid recovery. Within 2 weeks, the tick population recovered to the point where they exceeded the expected values in both plots D2 and D3. During week 6 and week 9 plot D1 was mowed, which brought the tick population below what was expected, an unintentional control mechanism. Plot D3 received the 3rd application of naled during week 9, which resulted in a 96% reduction of questing ticks. The recovery was now much slower, from week 9 through 12. The effect of the physical act of treating the ticks along roadside edges with water (W2, W3, Fig. 2) is negligible.

Although each individual analysis provided both significant statements and generalizations concerning the experiments, one analysis followed the other in a logical sequence to determine the most significant statements. Exploratory data analysis provided the justification for the transformation (Tukey 1977) of the raw data to stabilize the variances (plot to plot, week to week, etc.), and for the median polish to account for differences of pre-experimental tick populations. This analysis provided an insight into results that were confirmed by classical regression techniques. The multiple regression and simple regression resulted in almost identical statements (e.g. 20%

population decay rate). Simple regression assumed variable independence while the multiple regression did not.

Conclusions derived from all analyses are in agreement. There is an overall decline of the tick population during a season of about 20% per week, within the range reported by White et al. (1980). Spraying water on ticks had no effect on the population so treated. Low-volume sprays of naled resulted in dramatic drops of the population (82–97%) followed by gradual recovery, consistent with the mark-recapture study (White et al. 1980) recruitment phenomenon. Cutting of grass along tick habitats was statistically shown to reduce the expected questing tick population for a short term.

Acknowledgments

We wish to acknowledge Hilary Summer, Robert Dickeson and A. Lee Holcomb for their valuable technical assistance.

Literature Cited

- Benach, J. L., D. J. White, W. Burgdorfer, T. Keelan, S. Guirgis and R. Altieri. 1977. Changing patterns in the incidence of Rocky Mountain Spotted Fever on Long Island (1970–1976). *Am. J. Epidemiol.* 106:380–387.
- Clymer, B. C., D. E. Howell and J. A. Hair. 1970. Environmental alteration in recreational areas by mechanical and chemical treatment as a means of Lone-star tick control. *J. Econ. Entomol.* 63:504–509.
- D'Angelo, L. J., W. G. Winkler and D. J. Bregman. 1978. Rocky Mountain Spotted Fever in the United States 1975–1978. *J. Infect. Dis.* 138:273–276.
- Hattwick, M. A. W. 1971. Rocky Mountain Spotted Fever in the United States 1920–1970. *J. Infect. Dis.* 124:112–114.
- Hoch, A. L., R. W. Barker and J. A. Hair. 1971. Further observations on the control of Lone star ticks (Acarina: Ixodidae) through integrated control procedures. *J. Med. Entomol.* 8:731–734.
- Loving, S. M., A. B. Smith, A. F. DiSalvo and W. Burgdorfer. 1978. Distribution and prevalence of spotted fever group rickettsiae in ticks from South Carolina, with an epidemiological survey of persons bitten by infected ticks. *Am. J. Trop. Med. Hyg.* 27:1255–1260.
- Mount, G. A., J. G. Williams, C. S. Lofgren and S. A. White. 1968. Insecticides for control of the Lone star tick tested in the laboratory and as high and ultra-low volume sprays in wooded areas. *J. Econ. Entomol.* 61:1005–1007.
- , C. S. Lofgren and N. W. Pierce. 1971. Effectiveness of 22 promising insecticides for control of the lone star tick. *J. Econ. Entomol.* 64:262–263.
- Smith, C. N., M. M. Cole and H. K. Gouck. 1946. Biology and control of the American dog tick. *U.S. Dep. Agric. Tech. Bull.* 905. 74 pp.
- Sonenshine, D. E., A. H. Peters and G. E. Levy. 1972. Rocky Mountain Spotted Fever in relation to vegetation in the eastern United States. 1951–1971. *Am. J. Epidemiol.* 96:59–69.
- Teel, D. D., J. A. Hair and T. C. Randolph Jr. 1977. Continuous administration of famphur for control of ticks and bed bugs feeding on ruminants. *J. Econ. Entomol.* 70:664–666.

- Tukey, J. W. 1977. Exploratory data analysis. Addison-Welsey Publishing Co., Reading, Mass. 506 pp.
- Wharton, R. H. 1976. Tick-borne livestock diseases and their vectors. Part 5. Acaricide resistance and alternative methods of tick control. World Animal Rev. 20:8-15.
- White, D. J. and J. L. Benach. 1980. Control of *Dermacentor variabilis*. 1. Larval and adult susceptibility to selected insecticides. J. N.Y. Entomol. Soc. 89:16-22.
- , L. A. Smith and J. L. Benach. 1980. Control of *Dermacentor variabilis*. 2. Analysis of a mark-recapture study of a seasonal questing population. Submitted.

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Received for publication June 23, 1980.